THE OCCURRENCE OF ALGONKIAN ROCKS IN VERMONT AND THE EVIDENCE FOR THEIR SUB-DIVISION.

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CONTENTS.

GEOGRAPHY.

THE area of the Pre-Cambrian rocks forming the subject of this paper[1] is quite limited in comparison with the probable extent of these rocks in Vermont. Personal reconnaissance work has detected them existing from the town Stratton on the south to Rochester on the north, a distance of fifty miles. In only a part of this area has detailed work been done, viz.; from Weston to Chittenden. On the east the district is bounded by Plymouth Valley; on the west by Rutland Valley, an area of about 240

[1] The work, of which this paper forms a partial result, was done under the immediate supervision of Mr. Raphael Pumpelly, then in charge of the Archæan Division of the United States Geological Survey, to whom my greatest thanks are due for useful counsel and advice. It is not to be understood that he is necessarily in perfect accord with me in any views advanced here.

square miles. This area has a maximum width on the south of ten miles and a minimum width on the north of four miles. The delimitation of the Pre-Cambrian as just given is only approximate, as in many localities data for its separation from overlying rocks are lacking.

TOPOGRAPHY.

The Geological Survey has lately issued topographic maps of nearly all the territory embraced in the above-outlined area; in them the pronounced relief of the country is well shown. These maps are the Rutland and Wallingford sheets. An inspection of the topography reveals a line of high elevations on the west, with steep slopes to the east, and steeper slopes commonly on the western side. This line of mountains extends from the southern limit of the Wallingford sheet to the northern limit of the Rutland sheet, and is only broken by narrow transverse valleys where lateral streams come in from the east or southeast and join Otter creek in the Rutland valley. On the east side of the area a similar range of high mountains extends the same distance, but coalesces with the western line in the northern part of the Rutland sheet. The convergence of the two lines is geologically dependent on a narrowing of the series of folds, which originally mantled over the central part of the area. North of Ludlow mountains an offset to the east occurs which carries the line slightly to the east of the Wallingford sheet.

It will be noticed on the Wallingford sheet that there is a central area between the border line of mountains of relatively much lower elevations. From Copperas hill in Shrewsbury one observes that the mountains appear to encircle him with a line of much higher elevations. In a country of strong relief one is always impressed with a sense of being in the centre of a series of elevations of greater height than those in the immediate vicinity. But from Copperas hill the impression is borne out by a glance at the topographic maps. On the east and west are the two lines of mountains just described; to the south, but farther away, the country begins to rise towards the high peaks of Stratton and Somerset; to the north, just north of the town of Shrewsbury

the high summits of Mendon, Killington and Shrewsbury extending east and west shut off the view in this direction. The lowest part of this amphitheatre is just northwest of Cuttingsville where Mill Creek has cut down to an elevation of 1000 feet above the sea. Killington Peak marks the highest point to the north, 4241 feet. The Central Vermont Railroad finds the lowest pass in the southern part of the range through this amphitheatre at Summit Station, 1500 feet above the sea.

Standing on the summit of Killington a wilderness of mountains meets one's view; the Taconic Mountains on the west and southwest; the Adirondacks to the northwest; far away northeast the White Mountains are plainly visible and the sharp outlying peaks, Monadnock, Kearsarge and Wachusett are seen to the southeast. The summits of all these mountains, with the multitude of peaks in Vermont, have the appearance of a remarkably uniform height about which numerous narrow valleys are seen; their relatively uniform height can safely be referred to an ancient base-level plain, in which upon elevation the north and south gently-flowing streams were quickly cut along the linear limestone belts, hastening and causing the development of the torrential lateral streams that flow east and west from the Green Mountain divide. It is to this torrential character of the streams and the schistose nature of the rocks that the sharp, angular topography in large part seems to be due. Rutland and Plymouth valleys, some twelve miles apart on either side of the range, are deeply cut in limestone—the former at Rutland to a depth of 500 feet above the sea. The great cutting power of the streams flowing into this valley from the east is thus seen to be due to a fall of over 3000 feet in a distance of six miles. The Green Mountain divide is about midway between these two valleys. Relatively less pronounced topographical features characterize the amphitheatre; sharp, high elevations occur, which are capped by more resistant rocks than those making up the main central area. It is between the lower rocks of this central depression and the formation along the east and west borders and to the north that an unconformity separating the rocks

below the Olenellus quartzite into two periods is thought to occur.

GEOLOGY.

Outline of the views previously held regarding the structure and age of the Green Mountains.—As far back as 1845, Adams in his first Annual Report on the Geology of Vermont[1] referred to the "Primary" system the rocks of the main range of the Green Mountains as far as the state boundary, and eastward. Among the rocks mentioned under this head which occur in the area studied by me are Green Mountain Gneiss, Mica Slate and Talcose Slate. In this report these horizons are placed below the Stockbridge limestone and the associated quartzite of the Taconic, but their relative age is confessedly unknown. In his second annua report,[2] however, he leaves the problem as to whether these are "Taconic," "Primary," or "Metamorphic," an open question, but still inclines towards a belief in their primary origin. This belief is inferred from his statement that the evidence goes to show that the limestone and quartzite of Plymouth valley on the east side of the range is equivalent to the Stockbridge limestone and quarzite on the west side, making the core of the Green Mountains the older. Adams in no place makes the statement that the belt of primary rocks represents the axis of the range, and it is doubted if he had any clear conception of the relations of the rocks on the east and west sides of the Green Mountain divide. In 1847, however, Edward Hitchcock gave two sections in his text book of Geology[3] of the Green Mountain anticline partially and completely folded as we see it to-day. The anticline is represented as overturned slightly to the west, with a flat crest and a rude fan-shaped cross-section; the text[4] mentions that the strata grow newer as one goes westerly, although apparently the series is descending. Such a conclusion reached at that time is the happy result of a coincidence of schistosity and stratification at

[1] p. 62.

[2] Second Annual Report on the Geology of Vermont. Adams, 1846, p. 168.

[3] Elementary Geology, Edward Hitchcock, 1847, figs. 27 and 28, p. 37.

[4] Opus. cit., p. 36.

the localities examined by him ; in a general way the structure is that of an overturned series of folds, of an extremely complicated nature. These sections were made particularly to illustrate the structure of Hoosac Mountain, and the structure suggested in 1847 finds its verification in 1889[1] in Massachusetts, as far as the overturning of the anticline to the west is concerned. At that time little reference was made to the age of the rocks exposed along the axis, but they were mentioned as probably older than the Lower Silurian, while their relation to the younger rocks was not considered.

Zodack Thompson, in 1856, in considering the "Taconic System," makes reference to the structure of the rocks along the Green Mountain range[2].

He remarks that "one of the most marked peculiarities in the geology of Vermont is found in the general dip of the stratified rocks, which is, with a few trifling exceptions, toward a synclinal axis extending north and south near the center of the Green Mountain range." He notes a general westerly dip on the east side of the range, and an easterly dip on the west side. However, the question as to whether the Green Mountain rocks are really primary or post-Taconic was with him still in doubt, but he states that the weight of the evidence points towards the latter view, or more recent age.

In 1868, T. Sterry Hunt, after a study of the literature, while discussing Vermont geology, comes to much the same conclusion as Thompson.[3] To use his own words: "All the evidence, palæontological and stratigraphical, as yet brought forward, affords no proof of the existence in Vermont of any strata (a small spur of the Laurentian excepted) lower than the Potsdam

[1] See part 3, "Geology of the Green Mountains in Massachusetts," by R. Pumpelly, J. E. Wolff, T. Nelson Dale, and Bayard T. Putnam. Monograph U. S. Geol. Survey. Submitted in 1889. Not yet issued.

[2] Preliminary Report on the Natural History of the State of Vermont. Augustus Young. 1856. Extract from Zodack Thompson's address on the Natural History of Vermont. App. 6, p. 67.

[3] On some points in the geology of Vermont, T. Sterry Hunt, Am. Jour. Sci., 2d series, Vol. XLVI., 1868, p. 229.

formation * * * ." The gneiss of the Green Mountains is by him and by the geological survey of Canada referred to the Quebec group and a synclinal structure is assigned to the range probably largely on the basis of the views of Thompson. It is thus seen that Adams' suggestion of the anticlinal nature of the mountains and their "primary" age are passed over, as well as the more recent work of the elder Hitchcock, to which reference is made below.

Anything like a close study of the Green Mountains was not attempted until 1861, when the two Hitchcocks finished their work on the geology of the state.[1] Under the head of Azoic Rocks,[2] Charles H. Hitchcock places the Vermont rocks occurring east of the Stockbridge limestone as far as the Connecticut river, and includes therein the basal quartzite of Emmons' Taconic system, although the elder Hitchcock admits finding therein traces of life in the shape of Scolithus and a species of Lingula[3] which were not deemed sufficient evidence to warrant classifying this horizon with the fossiliferous rocks. The younger Hitchcock divided the azoic rocks as follows: Gneiss (Adams' Green Mountain Gneiss) hornblende schist, mica-schist, clay-slate, quartz-rock, talcose schist, serpentine and steatite and saccharoidal limestone. The most western member, the quartz-rock or quartzite with its associated conglomerate is mapped as extending the whole length of the state. Just north of the area studied by me it is represented as thinning out and giving place to "talcose conglomerate."[4] On the east side of the mountains a narrow strip is colored in extending through the towns of Plymouth and Ludlow. Lithological similarity is used as a basis for the correlation of the conglomerate, which underlies the "quartz-rock" at Wallingford with the Shawangunk Grit or Oneida Conglomerate of New York. The quartzite or quartz-rock is referred for

[1] Geology of Vermont, 1861, 2 volumes.

[2] Opus. cit. Vol. I., pp. 452 to 453.

[3] Opus. cit. Vol. I., p. 500.

[4] Opus. cit. See geological map of Vermont. Pl. I., Vol. I.

palæontological reasons to the Medina, and the hypothesis is advanced that by the removal of silicates by circulating waters metamorphosis of the quartz-rock to the conglomerate has taken place. Reference will be made again to this conglomerate in the following pages. Under the head of Gneiss, rocks of great variation are grouped. Eight principal varieties dependent on accessory minerals such as hornblende and epidote are enumerated. The gneiss is represented as a slightly curving band, extending from the Massachusetts line nearly to the north end of the state, gradually narrowing to a point. In the south-eastern part of the state another shorter lense is mapped, but this has not been explored by the writer. The relations of the gneiss to the conglomerate or quartz-rock are not dwelt upon, but many phases are assigned to metamorphosed Lower Silurian rocks, while the probability that even older rocks may be exposed along the anticlinal axis in the range proper, or to the east is regarded as a possibility. A deficiency of feldspar is remarked upon; because of this peculiarity, according to Hitchcock, Adams called it "Green Mountain Gneiss to distinguish it from true gneiss."[1] Seven years later (1868) C. H. Hitchcock abandoned his theory as to the age of the quartzite,[2] and in a new classification refers it to the Potsdam group. The Talcose conglomerate is placed in the "Lauzon" group of the Lower Silurian, while to the Eozoic system the Green Mountain gneiss is assigned. In placing the gneiss in the Eozoic he does not infer that it necessarily is older than the Cambrian or Huronian. Several reasons are enumerated for referring it to this system, the strongest one being the evidence afforded by the occurrence of pebbles in the Talcose comglomerate at the base of the Potsdam derived from gneissic rocks. An unconformity beneath the Potsdam points to the Eozoic age of the lower rocks.[3]

The suggestion made by Adams (above mentioned) that the Green Mountains are an anticlinal fold, is followed, in

[1] Opus. cit. Vol. I., p. 454.

[2] The Geology of Vermont, Proc. Amer. Asso., 16th meeting, 1868, p. 120.

[3] Opus. cit. p. 122.

1861, by the statement of the elder Hitchcock that such is the structure. Numerous sections across the range are given in which its anticlinal nature is brought out. Much evidence is adduced in the text pointing to the same conclusion based mainly on the occurence of a quartzite and conglomerate on both sides of the range associated with limestones. Edward Hitchcock, in 1847, had published sections which represented the range as an anticline slightly inverted by overturning towards the west. Adams, in 1845, had somewhat disconnectedly stated that the "granular quartz-rock" of the Taconic had an inverted dip,[1] but did not include in the Taconic rocks east of the quartz rock.

In all, the geology of Vermont (1861), contains twelve sections east and west across the State. Of these, eleven traverse the Green Mountain gneiss; the four southern ones show several synclines and anticlines in the gneiss; section V, one broad anticline; sections VI, VII, and VIII represent the anticline overturned to the west; and in sections IX, X, X^a, and XI the gneiss is given a simple anticlinal structure. On the west side of the range, in all sections except the fifth, the quartz rock is given an easterly dip of varying angle due to inversion. With one exception, at North Bennington, where the quartzite dips easterly at an angle of 5° to 20°, nearly in the position it was laid down, the writer has not seen an easterly dip in the rock along this belt as far north as Pittsford. The rock is usually quite massive and flinty, and bedding is not discernible. An easterly-dipping jointing is easily mistaken for stratification. Rocks immediately below have a lamination that dips easterly at a high angle, and the inversion argued is based largely upon observation on this structure; the coincidence of lamination and bedding along the western border has already been spoken of as the probable reason of the elder Hitchcock's accurate decipherment, in 1847, of the real altitude of the main axis of the mountains in Massachusetts. In 1868 the younger Hitchcock reiterated the interpretation

[1] First Annual Report on the Geology of Vermont, 1845, p. 61.

of his father, as to its anticlinal structure, and cites as proof the supposed equivalence of the "Potsdam" and "Levis" rocks on both sides of the range in Wallingford and Plymouth.[1]

THE PROBLEM OUTLINED.

From the opinions held as to the age, character, and structure of the Green Mountain axis just given, the main facts that stand out most prominently are that the centre of the mountains is occupied by strata to which the name gneiss is universally given, and that bordering this, on the west, occurs a terrane variously called "granular quartz," "quartz rock," and "quartzite," by different authors, together with an associated conglomerate. These last two rocks have been referred to various horizons from the Azoic to the Medina sandstone. Most geologists have grouped the central gneiss among the oldest, although Thompson considered it more recent than the Stockbridge limestone.

The relations of the conglomerate to the quartzite are by no means so simple as the older geologists were disposed to believe. Between the conglomerate and the quartzite there is an extensive series of metamorphosed sedimentary rocks which have been overlooked in the past, and which are in part the subject of this paper. Beneath the conglomerate horizon the gneisses and other rocks occurring in the amphitheatres, with their interstratified limestones and quartzites make a second series composed wholly or partly of sedimentary rocks separated from the first, of which the conglomerate is the base, by an unconformity sufficiently well identified to warrant a sub-division of the Pre-Cambrian Algonkian terranes into two series.

REASONS FOR REFERRING THESE ROCKS TO THE ALGONKIAN.

It is due to the labor of Mr. Walcott that the age of the quartzite on the western border of the range has finally been determined definitely. Upon palæontological evidence he refers it to the Lower Cambrian horizon and makes it equivalent to the red sand rock of Georgia, Vermont; the latter being an offshore, and the former a near-shore deposit. In his Cambrian

[1] The Geology of Vermont, Proc. Amer. Assoc. 16th meeting, 1886, p. 121.

correlation paper[1] Mr. Walcott represents, probably hypothetically, the quartzite lying unconformably upon Pre-Cambrian (Algonkian) strata. The evidence for a time-break at Clarksburg Mountain in Massachusetts is undoubted, but farther north the relation of the quartzite to the subjacent rocks is much more obscure. As to the age of the subjacent terranes in Rutland County, Mr. Walcott refers them to the Archæan.[2] Since the Olenellus fauna, as determined in Vermont, delimits the base of the Cambrian horizon, all the sedimentary rocks below (adopting the classification of the U. S. Geological Survey) must be referred to the Algonkian. As mentioned above, the quartzite along the border is considered a near-shore deposit, and as such, it is evidence in itself of an approximate subjacent delimitation of the Cambrian sediments. On lithological grounds alone it would be correlated at once with the Potsdam on the eastern border of the Adirondacks, not thirty-five miles west of Wallingford, where the base of the Upper Cambrian is plainly seen resting unconformably upon the lower gneisses. The Potsdam is only faintly conglomeratic at the bottom, and the same is true of the quartzite in Vermont; so that in Vermont, at least, we are apparently without a true basal conglomerate in the Cambrian. The Lower Cambrian lies directly upon granitoid gneiss twenty-five miles south of Wallingford, where the contact is depositional with no conglomerate whatever. These occurrences indicate that we are not obliged to postulate still lower members of the Olenellus horizon on the ground that the base as there shown is not delimited by a conglomerate. In all the localities in Vermont examined by me a reversed dip in the quartzite on the west side of the range has not been observed; in the stratified series just below overturns occur along this line. This may be cited as evidence of discordance at the base of the Olenellus quartzite, as it is extremely unlikely that pronounced overturning could have taken place without involving the quartzite in its folds. That a thick

[1] Correlation Papers, Cambrian; Bulletin U. S. Geological Survey, 1890, Pl. II, theoretical cross-section at bottom of page.

[2] See Geologic column No. 8, opus. cit. p. 366.

bed of massive quartzite might not be affected by minor folds is recognized, as it is well known to be among the most resistent rocks. The series below, however, possesses quartzites still more massive and flinty, rocks which have been involved in close flexures as sharp as those in fissile associated beds. Through Massachusetts and southern Vermont the quartzite is remarkable for its persistence. The series immediately beneath is extremely variable in character and thickness due to original deposition and to the metamorphism that it has suffered. This series may be wanting, as on Clarksburg Mountain and at North Bennington, Vermont, where the quartzite lies unconformably upon crystalline gneisses.

In Walcott's hypothetical section across this continent, the Cambrian ocean is represented as sending a long arm up the Rutland Valley not covering the Green Mountains or the Adirondacks. Careful search through the Green Mountains proper has not resulted in finding any traces of the quartzite, there is no evidence that it once mantled over the range, although it is not unlikely that the Plymouth Valley was once occupied by Cambrian waters. There are abundant occurrences, however, of the lower series in the heart of the range, where many of the highest peaks are capped by one member or another. There is stratigraphical and microscopical evidence that this series has undergone repeated disturbances; the quartzite exhibits but one. This fact cannot be used legitimately as evidence of disparity in age, as it is probable that the thick bed of quartzite stood like a bulwark among more variable, less-resistant strata, not taking part in and not recording orographic movements unless of extreme intensity. It should not fail to be stated that in many localities the quartzite lies directly upon fissile mica schist, the upper member of the series below in apparent conformity therewith, and the difficulty of referring the schist to the Lower Cambrian or the Algonkian is apparent. I am disposed to believe it of the latter age and to make it the uppermost member of an upper series with the metamorphic conglomerate delimiting the series below. There are many reasons for this view, some of

which have been given. The limits of this paper will not permit anything like a full analysis of the evidence, which must be reserved for some future time. It seems generally, however, to be accepted that sedimentary rocks below the Olenellus horizon shall be considered to belong to the Algonkian. But few forms of the characteristic fauna of the Lower Cambrian are known to extend below this horizon; no fossils have been discovered in the big Cottonwood section in Utah, where 12,000 feet of silicious states and sandstone lie conformably below the olenellus zone. It is safe to assume that through such a vertical extent of rock the typical Olenellus fauna will not range, and consequently part at least must be placed with the Algonkian. That a part of the Vermont rocks immediately below the quartzite may be proven in the future to belong with the quartzite above is recognized, but the trend of the evidence collected by me points toward its classification in part at least with the Pre-Cambrian sedimentary rocks. Without commenting, the reasons for and against this view may be concisely stated, as follows: 1. Extreme diversity of the metamorphic series, or great lithological difference, as compared with the quartzite horizon. 2. Evidence of profound orographic movements in the latter not observed in the former, the folds often occuring overturned to the west. 3. Occurrence of the quartzite reposing discordantly upon granitoid gneiss not far south of the area under discussion and also near by in New York. 4. The near-shore character of the quartzite. 5. The fact that the quartzite does not occur in the heart of or to the east of the range, whereas the series below has been traced across the mountains. 6. In general, the converging of the gneiss-area shown on Hitchcock's map of the State[1] indicating a northerly-pitching anticline, and in detail shown in small flutings, while the quartzite does not exhibit this feature. 8. The occurrence of undoubted Algonkian rocks near by, south of Hoosac Mountain in Massachusetts identified by Mr. Emerson,[2] who finds Lower

[1] Geology of Vermont, 1861.

[2] See Geological Atlas of the United States, Hawley Sheet, 1892, B. K. EMERSON. Members of the Algonkian Period are briefly described on Sheet No. 4.

Cambrian conglomerate gneiss resting unconformably upon the upturned edges of a coarse gneiss associated with coarsely-crystalline limestone (Emerson's Hinsdale limestone). A line of Algonkian rocks extends southward from Hoosac Mountain (including the Stamford gneiss forming the core of the mountain) in a belt of oval areas across the Berkshire County Plateau. On lithological grounds these rocks would be correlated with some members of the Mount Holly series of Vermont to be described below. They may, however, be equivalent to the upper series of the Algonkian which has suffered less metamorphism to the north. The lack of fossil remains in the lower series cannot be used as evidence, since metamorphism has probably obliterated all traces of them. A disparity between induced structures in the two belts is also of no value as the quartzite has not recorded the regional cleavage owing to its massive character. Rocks stratigraphically above it, however, may have had the cleavage developed. The evidence against this delimitation is furnished by the apparently conformable mica schist, which, as a rule, accompanies the quartzite, and more locally other members of the series as well, which may have contained the Olenellus fauna. It must be left for future work to determine beyond dispute the relations of the series immediately below the Olenellus zone to the quartzite, whether the rocks are conformable or unconformable; if the former, whether the delimitation of the Lower Cambrian shall be placed above the mica schist or below it. Tentatively, the series just below the quartzite, the mica schist at the top and the conglomerate at the bottom, will be considered wholly or in part of Algonkian age. The separate members of this series with estimated thicknesses will now be described.

THE UPPER OR MENDON SERIES OF THE ALGONKIAN.

As far as known the best section of these rocks occurs in the town of Mendon, one mile north of Mendon village, on the west slope of Blue Ridge Mountain (Rutland Sheet). All the members identified occur here, although no single section thus

far examined has all the members developed characteristically or of maximum thickness. Each member thins out and thickens along its strike in the most remarkable manner. On Nickwacket Mountain, just north of the Rutland Sheet, for example, the pebbly, micaceous quartzite member attains its greatest thickness, and the pebbly limestone as well; while in the heart of the range, east of the Chittenden flats the lower quartzite-conglomerate horizon attains its maximum development. The mica schist is best seen along the Mendon section. Provisionally, therefore, for descriptive purposes the name Mendon Series will be given these rocks.

That the relations of the different members of this series could be worked out seemed for a time a hopeless task, as it was subject to such great variations in character, and was so intimately folded, but the order given below, from less disturbed localities is correct within narrow limits. The thickness of the different beds is estimated, such estimates being based upon great familiarity with them in widely-separated localities, and under various habits due to metamorphism. The estimates are well within the limits of maximum variation.

Beginning with the Olenellus quartzite which strikes N. 5 W. to N. 5° E., the next rock, as mentioned above, descending geologically, is a mica schist. It occurs along the west base of the hill, situated in the northwest corner of Mendon. Near the quartzite it appears conformable, but as one ascends the hill, going east, the rock becomes more crumpled; two hundred feet from the quartzite the stratification has been practically destroyed, while the regional schistosity, characteristic of the Appalachian range in New England, takes its place. This induced structure, along the borders of the range strikes quite uniformily N. 10° to 15° E., dipping commonly between 60° and 80° easterly, although westerly dips are noticed. The structure of the schist consists of minute plications and larger ones many feet across, closely folded and often overturned to west. Minute faulting along the axis of the crenulations has produced the schistosity (ausweisungschiefer) which has been

mistaken for the dip by the early workers in this region. A line drawn tangentially across the apices of the serratures shows the dip to be some 45° westerly in the upper (westerly) part. In this section the schist may be safely assumed to have a thickness of 800 feet. In some localities it is not over 50 feet thick, but just south of Chittenden village more than 1000 feet occur. All through the area the schist carries abundant lenses of secondary quartz introduced along the bedding and cleavage planes. These are considered genetically to be the excess of silica, resulting in great part from the decomposition of silicates originally in the rock, the alumina and potassium going to form the muscovite. Phases of the rock are without such lenses and are nearly free from quartz ; other phases are largely quartz layers with thin folds of mica between. Some phases carry secondary feldspars, but they are exceptional. Under the microscope the normal constituents of the schist are seen to be a varying percentage of chlorite, a great deal of muscovite in slender, closely-packed plates and quartz in thin layers and scattered through the rock. Biotite in larger flakes is also universally present, with occasional feldspar grains.

Beneath the schist is the micaceous quartzite horizon, poorly represented in this section, but on Nickwacket Mountain having a thickness of 500 feet at least, and carrying several thin beds of crystalline limestone. Here there are not over 100 feet, with no interstratified limestone beds. It has scattered through it abundant pebbles of feldspar (microcline and orthoclase) besides quartz. The pebbles are small and have undoubted clastic outlines. Owing to their occurrence, this horizon is particularly easy to identify. Its strike is a little west of north, and the dip 80° easterly. Going east from the Olenellus quartzite the dips have grown continually steeper and now we find the rocks overturned to the west. This horizon presents many phases ; traced south five miles it becomes a muscovitic schist, highly contorted, in which there is no evidence of detrital material ; traced eastward towards the heart of the range, when caught in synclinal folds it is a granular, micaceous gneiss. Secondary feldspars

have been developed, but the larger clastic feldspar may be still detected in a fine-grained ground mass. On White Rock Mountain its place is occupied by a well-marked sandstone carrying some biotite. Microscopically the rock is made up essentially of small grains of clastic quartz. The larger pebbles of quartz and feldspar varying much in abundance in different localities. In the heart of the range a gneissose phase is produced by granulation and by development of pale-green, pleochroic muscovite and glassy plagioclase from the feldspar pebbles. The mica in the most massive phase is also green muscovite.

Immediately below the quartzite are fifty feet of pebbly, crystalline limestone, the pebbles being largely feldspar, like those in the quartzite. A narrow valley occurs here in this section due to the relatively rapid removal of the limestone. Nickwacket Mountain along its northern peak exhibits the best development of this rock, where its thickness may be safely estimated at 400 feet. It is only locally pebbly there in contact with quartzose layers or the main body of the quartzite above. Lack of persistence characterizes this work as one would expect. This seems to be due to want of, or to differences in, original deposition in many localities; to its alteration to other minerals; to its removal by solution, and to its being squeezed out during folding. The rock is locally graphitic and usually quartzose, especially where it occurs in thin beds in the micaceous pebble-bearing quartzite. Phlogopite is common in little flakes in some dolomitic varieties. All through the mountains of the Rutland Sheet it forms an easily-recognized horizon. Near the summit of Pico peak, just north of Killington, it occurs, and by its rapid removal it has given rise to escarpments on the southwest slope of the mountain.

Some fifty feet of green muscovite schist occurs next below, which may be considered a laminated phase of the micaceous quartzite which usually appears below the limestone. This grades downward into a flinty quartzite along this section. Locally the quartzite carries pebbles of quartz and as one goes east it is seen to grade into the metamorphic conglomerate that

has become so classic through the contributions of the elder Hitchcock. This horizon is one of extreme variability and no one name can be given it that will have anything like a general descriptive application. Further south Mr. Wolff has described it as a conglomerate-schist,[1] but there the percentage of feldspar, both secondary and original is large and the rock has a marked schistosity. Another phase from the Mendon section is a well-developed conglomerate in which the pebbles vary in size from a pea up to small boulders. The larger ones are nearly all of vitreous quartz, many of a fine blue color. At East Clarendon nearly all detrital material is obliterated by the shearing action that has developed the perfect lamination observed there. Exposed south of Mendon village this horizon is a vitreous massive quartzite, probably 500 feet thick, devoid of all evidence of stratification. Three miles south of there, the quartzite has disappeared and a well-laminated muscovitic gneiss, similar to that occuring at East Clarendon and Bald Mountain east of Rutland, takes its place. One mile north of Chittenden a remarkable phase occurs; the rock as a whole is still a vitreous quartzite, but it is made up almost entirely of angular and rounded boulder-like areas of the same material. The boulders seem to represent in part an original conglomerate. If boulders of a composite nature were deposited with those of quartz, the silicates have been converted into what little ground-mass the rock now possesses. After the rock was cemented into a vitreous quartzite, brecciation took place, and today we see a mixture of genuine boulders, some having a diameter of several feet, and pseudo-boulders of larger dimensions, some angular and others having rounded outlines. imitating genuine clastics. The former are identified by their occasional occurrence in a matrix or cement that has protected them from distortion or granulation. East of Chittenden flats an even greater development of quartzite occurs where its thick-

[1] Metamorphism of Clastic Feldspar in Conglomerate Schist, Bull. Museum Comp. Zoöl. Whole series Vol. XVI., No. 10, Plate II, shows two excellent microphotographs of this phase of the conglomerate where the clastic material is nearly obliterated.

ness is not less than 700 feet. Where an excess of shearing motion has operated, a well-laminated schist has resulted, examples of which may be seen at the base of the conglomerate in the Mendon section and extending north and south from there; on the summits of Pico, Killington, Mendon, Little Killington, and Blue Ridge Mountains, and in countless other localities.

Many phases of this schist occur characterized by accessories such as chlorite, biotite, and magnetite. An important and wide-spread variety carries ottrelite in prisms and radiating bundles.[1] Muscovite predominates over other micaceous minerals, both colorless and green varieties occurring, while feldspar is only sparingly present. All the varieties of this horizon occur in great confusion, grading into one another vertically and along the strike. In my notes the most schistose variety has been called Killington schist, and this with the green gneissose phase are the two most common occurrences of the rock. It seems preferable to adopt the name conglomerate-gneiss for this horizon as it is descriptive of its present mineral constitution and suggestive of its past history. All the evidences of profound dynamic movement observed in this series are observable in the quartzite along the Mendon section. In fact, no rock in the Mendon series bears evidence of so great disturbances.

Considering 350 feet to represent the thickness of the quartzite and conglomerate at this point, the total thickness of the section is approximately 1,300 feet. It is probable that in some localities there may be 2,000 feet of strata, and in the northern part of the State no doubt the formation is much more greatly developed. As a whole it is subject to great variations in thickness, and may decrease to two or three hundred feet, as on the south end of Bear Mountains in Wallingford. The relations of the conglomerate-gneiss horizon to the underlying rocks will be

[1] This phase was described by the writer in the American Journal of Science, Vol. XLIV., Oct., 1892.—An Ottrelite-Bearing Phase of a Metamorphic Conglomerate in the Green Mountains.

considered after a general description of the rocks comprising the second or lower division of the Algonkian terranes has been given.

THE LOWER OR MOUNT HOLLY SERIES OF THE ALGONKIAN.

In the amphitheatre already described, the rocks of this series occur well-developed in the towns of Mount Holly and Shrewsbury and extend south probably to near the Massachusetts line. They are perhaps no more characteristically developed in Mount Holly than elsewhere to the south, or possibly to the north, but they are best known to me there of anywhere in the State. It seems best, therefore, to designate the rocks of this central area, or core of the Green Mountains, the Mount Holly series.

In nearly every way the core rocks are contrasted with the Mendon series; these differences will be emphasized below when the question of the relations of the two series will be discussed. A description of the different consecutive members of the series cannot be given, as the rocks are too variable in character, and dynamic action has involved them in such complications. No approach has been made in the determination of the order of their occurences, and it is doubtful if such a sequence will be made for years to come, unless more discriminating criteria are forthcoming. Many unlike members there are, but they are characterized by no presistence of horizon, or if they are, metamorphism has obliterated all distinguishing features. The area appears as a multitude of patches of different kinds of rocks, whose relations with one another seem impossible of solution. Unlike the Mendon series, there is no pronounced northerly lamination agreeing in the main with the genuine strike of the stratification. The structure here is in part due to zones of unlike mineralogical composition; most of the igneous rocks have been well laminated and the gneisses and schists have their characteristic arrangement of constituent minerals.

A detailed description of all the varieties of rock occurring will not be attempted here; some of the more noteworthy areas will be

briefly mentioned. Along the south slope of a hill just south of Mechanicsville, a section is exposed showing fine-grained biotite gneiss at the base, passing imperceptibly into a sugared quartzite above. This in turn is overlain by coarse saccharoidal limestone; and a muscovitic, garnetiferous schist overlies this, capping the summit of the hill. These rocks strike in general east and west and dip northerly. A section on the southwest slope of Ludlow Mountain, two miles southeast of here, exhibits at least two beds of coarse limestone grading into tremolite and green hornblende, interstratified with layers of schist. These rocks strike west of north and dip easterly. On the southwest slope of Saltash Mountain a bed of tremolitic limestone interstratified in biotitic gneiss trends northwest. At Northam village, a similar coarse limestone occurs associated with a vitreous quartzite, a laminated eruptive rock and a rusty muscovitic schist. All through the core there are patches of these coarse limestones in a great variety of association, such as with coarse augen-gneisses (a common occurrence), quartzites, schists, and other rocks. Fine-grained, blue marbles are present in two or three localities. In all cases the limestones are in irregular lenses, and are extremely local; their occurrence with coarse gneiss affords no evidence of structure; these scattered, irregular outcroppings and differences of association make them impossible of correlation. There may be two horizons of limestone in the core or there may be a dozen. The same is true of the quartzites and other sedimentary rocks. Limestone belts are, however, frequently identified by their metamorphosed equivalent, tremolite, or in rare instances, serpentine replaces the limestone. The Mount Holly series has scattered all through it these undoubted areas of sedimentary rocks recognizable where from manifold causes they have escaped destruction or metamorphism, and their clastic characters have not been obliterated. They probably represent remnants of a once great sedimentary series older than the Mendon series.

The rocks associated with the evident clastics present a great variety of texture and mineral composition. Thin sections show, however, that the differences are mainly due to variations

in grouping of the component minerals rather than to differences of composition. Gneisses are most common, occurring as fine-grained, chloritic rocks or coarse biotite, augen-gneisses. A brownish coarse gneiss with porphyritic crystals of orthoclase extends in intermittent outcrops from Wilcox Hill on the north to Button Hill on the south, a distance of eight miles. This rock carries both biotite and muscovite, the latter evidently derived from the feldspar. In Eastham, Northam, and east of Bear Mountain, there are areas of coarse biotite gneiss with interstratified beds of quartzite and limestone. Fine-grained, chloritic schists and gneisses are abundant, as on the summit of Saltash Mountain.

The area immediately about Mount Holly village on the Central Vermont Railroad, is characterized by a great number of amphibolites. These occur as schists, either intrusive or extrusive, and as dikes, cutting one another, and the country rock. They occur interlaminated with various rocks—quartzites, gneisses and schists, and possess the local schistosity of the enclosing rock. This is as true of the dikes as of the sills, affording a conception of how far removed from any key to the real stratification is the lamination of these rocks and how faulty geological interpretation must be when deciphered on the basis of induced structures. Aside from the interest one naturally feels in eruptives as old as these, their importance as evidence in separating the Mendon from the Mount Holly series cannot be overestimated. Modern basic dikes of camptonite and other igneous rocks traverse the core rocks, but they are younger than the last disturbance of the Green Mountains, cutting Algonkian and Cambrian rocks alike.

Following the accepted definition of the Algonkian rocks, this lower series as well as the upper must be grouped as Algonkian. Although possessing many rocks undoubtedly igneous, and others whose origin is problematical, there is a considerable development of genuine sedimentary rocks, warranting us to place the whole series among the Algonkian. The evidence for this sub-division, which is based upon manifold differences between

the Mendon and Mount Holly series and their associated phenomena, will now be considered.

EVIDENCE OF DISCORDANCE BETWEEN THE MOUNT HOLLY AND MENDON SERIES.

Lithological differences.—These are many, and furnish important data for the classification of the two series into two divisions. A hasty description has already been given of the upper series and a still more imperfect one of the series below, which, owing to its vast variety of rock phase, hardly warrants a detailed description of each rock. In a large way it may be said that the upper series is prevailingly schistose; the lower prevailingly gneissic. The rocks of the upper series can all be referred indisputably to a sedimentary origin; part, at least, of the lower are of igneous origin, and a still larger part afford no criteria which will enable us to assert their origin. Coarsely crystalline limestones occurring in the core have in no case been detected in the upper rock, and pebbly limestones or quartzites are never met with in the Mount Holly series. Along the western border of the range, from Sunderland to Chittenden, none of the core rocks are seen interstratified with the Mendon series. An association sometimes occurs, but only when there is evidence for a faulted relationship. In the amphitheatre, where the lowest rocks occur, none of the upper series have been found. Farther north the lower terrane makes up but a small part of the surface rocks; the Mendon series capping all the prominent mountains as far north as Nickwacket Peak. The chaotic occurrence and lack of discoverable sequence in the core rocks find no parallel in the relatively persistent and orderly arrangement of the upper series. To the eye the core rocks have an older look; they are commonly loose-textured when weathered, crumbling often in the hand. Under the microscope, the cause for this is readily seen in the universal granulation that the rocks have suffered, a phenomenon strongly in contrast to the more coherent, less-sugared rocks of the border. Other differences in the two series are found in their mineralogical composition as a whole. Such differences

may well be due to unlike environment making deductions in favor of unconformity to a certain extent misleading, but the contrasts noticed are too strongly marked to admit of dispute as to cause.

The gneisses and schists of the older rocks are characterized by a wide-spread development. Colorless muscovite, chlorite, orthoclase, biotite, and quartz occur as essential constituents; epidote, zoisite, titanite, and garnets occur as accessories. Of these, the first four minerals occur much more sparingly in the upper series; the last three are not remembered to occur at all. Phases of the lower limestones carry tremolite or serpentine, while dark hornblende occurs in abundance. Orthoclase is relatively much less abundant in the border rocks where it occurs frequently as pebbles. Pale-green, pleochroic muscovite, secondary plagioclase, magnetite, and ottrelite, so common in the upper series, are much less abundant in the lower series; green-muscovite and ottrelite are not known to me in the central area. The limestones of the two belts may also differ as to the percentage of carbónate of magnesium present. No investigation of this subject has been attempted.

Reference has already been made to the metamorphosed basic igneous rocks, amphibolites, of the central area. One of the best sections of these rocks is displayed in the railroad-cut at Summit station, where they are exposed for nearly half a mile. Numerous separate members can still be distinguished in the mass by textural variations. They are cut by dikes of the same material and also by more modern dikes of camptonite. Such a series of amphibolites probably represents a period of volcanic activity, antedating the Cambrian, of great areal extent. Nearly everywhere, where these lower rocks are exposed, amphibolites are present also. To the north they occur only in scattered patches associated with granitoid gneiss; to the south reconnaissance work has not detected them, but they probably occur there. Mr. Wolff has described an amphibolite from a hill situated about one mile south of Mount Holly station, and he refers

it with probability to an original diabase.[1] Remains of an original bisilicate (augite) can still be found in the rocks. Whether diabase or basalt their occurrence in sheets traversed by dikes of the same material and their great abundance lead me to consider them surface flows or intrusives. Their abundance may be cited as evidence of extrusive origin since it is extremely unlikely that any area, reasoning from analogy, would be traversed by so large a number of intrusives. This view is also sustained by the fact that diabases and basalts are prevailing surface flows. Such regions as the Triassic (Newark) of the eastern United States, Keweenaw Point, the western plateau, and the Deccan being examples. Their restriction to the Mount Holly series not only points to their extrusive origin, but whatever their origin they afford almost positive evidence of an unconformity at the top of the series; if intrusive, we should naturally expect to find them occurring in the Mendon series, which is not the case; if extrusive, their occurrence only in the core rocks is even more in favor of the proposed subdivision. As to the importance of the evidence afforded by these rocks no better confirmation can be found than the following from Van Hise.[1] "Eruptive rocks are often an important guide in determining structural discordances. These are valuable when the older series has passed through an epoch of eruptive activity before the newer series was deposited. In such cases, bosses, contemporaneous or intrusive beds, volcanic fragmental material or dikes may occur in the older series which nowhere are associated with the newer. It is possible, of course, that eruptives may penetrate the inferior members of a series and never reach the higher formations; but if it is found that the supposed inferior series is associated with abundant material of igneous origin which never passes beyond a certain line, it is almost demonstrative evidence of the later age of the newer series."

[1] Geology of the Green Mountains in Massachusetts, by R. Pumpelly, J. E. Wolff, T. Nelson Dale, and Bayard T. Putnam, Monograph U. S. Geol. Survey, Part 3, submitted in 1889.

[1] Correlation Papers—Archæan and Algonkian, Bull. No. 86, U. S. Geol. Survey, p. 520.

Structural differences.— Evidence afforded by a study of the structure in the two series, both original and induced, has an important bearing upon the separation of the two terranes. Of first importance may be mentioned the relatively orderly strike of the lamination and bedding of the upper series in comparison with the strike and disordered succes-

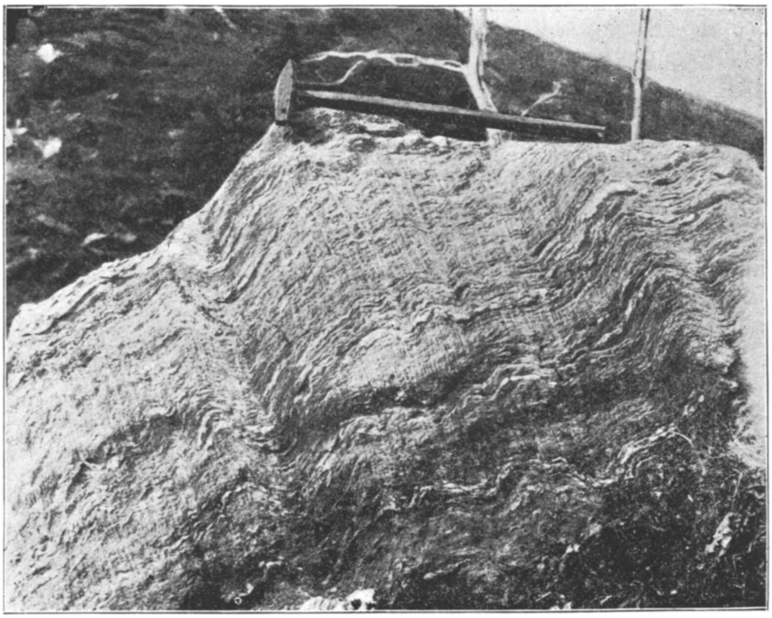

FIG. 1. Initial development of strain-slip cleavage, dipping to the right in a schistose phase of the conglomerate-gneiss horizon. The fluted bedding planes are seen dipping to the left. Under the microscope the faulting of the sharp crenulations is plainly visible with secondary formation of muscovite along slipping planes.

sion of the core rocks. The Mendon series in many localities is flexed into minute puckerings and minor folds having northerly pitching axes overturned to the west. Along the western line of the folds, and in synclinal troughs, sharp crenulations are developed; on the backs of folds stretching and consequent schistosity are best shown. When the sides of the crenulations are forced to move over each other strain-slip clear-

age is produced. A beautiful example of this is seen in Fig. 1, from the schist phase of the conglomerate gneiss two miles north-east of East Clarendon, near its contact with a coarse underlying gneiss. Blue Ridge and Pico Mountains are now capped by schist produced upon the back of folds. Close folding with axes striking nearly north and south only occurs in the amphitheatre near the summit of the greatest elevations, as on Mount Holly—a hill about a mile south of the station by that name—and near the contact with the Mendon series. The rocks of the core have no presistent strike and dip, neither of schistosity nor bedding; east and west strikes are as numerous as those trending north and south and the dips are as variable. Throughout the core the gnarled and tortuous folding of the strata represents the effect produced by the operation of repeated periods of mountain-building action of enormous force, directed not always from the east and west as in the Mendon series, but from the north and south as well.

A careful study of the Mendon series recognizes but two periods of orographic disturbance, the second acting along approximately the same lines as the first. This is well-indicated under the microscope, and in the field it is beautifully shown at North Sherburne where the strike of the rock (a conglomerate) is N. 25° W.—a trend produced by the first period of folding. The schistosity of the Green Mountains traverses this obliquely, making an angle of 35°–40°, striking N. 10° to 15° E. Both structures dip easterly at a variable angle. Forces that induced the regional lamination of the range could not have produced the great variety of trend observed in the folding of the Mount Holly series. The question of difference of environment of the central or lower parts of anticlines as compared with the outer must not be overlooked. All the phenomena go to show that the superior or Mendon series was above the neutral zone and that great slipping, stretching and crumpling took place therein dependent upon position in this belt. Below the neutral zone during the folding of the Mendon series undoubtedly most of the core rocks were placed where crushing would largely

exceed shearing and the development of the regional schistosity would not be expected. It is nevertheless true that the core rocks, although as a whole more massive than the border series, have in most localities a pronounced lamination not always due to the formation of micas, as in the Mendon series, but frequently the result of a rearrangement of the chemical combinations of the rock brought about by metasomatic and dynamic agencies. This is shown by the formation of amphibolites from some basic eruptive rock and by banding produced by the parallel injection of pegmatitic veins along the schistosity. If the core rocks were below the neutral zone during the folding that induced the regional clearage in the border series, then manifestly the intricate flexing of the inferior rocks was developed before the deposition of the Mendon series; if the core rocks were above the neutral belt they should have the normal lamination and characteristic folding universally occurring in the upper series, which is not the case.

A coarse granitoid gneiss and some associated quartzose sedimentaries occurring at North Sherburne are characterized by hundreds of minute faults to the square foot, having most divergent trends. That this was an area below the zone of neutral motion, thus permitting compensation by faulting or crushing is not tenable since the rocks are not more than 300 feet below a metamorphosed conglomerate, in which no faulting of this nature has taken place. In this phenomena we have more evidence pointing to the conclusion that the core rocks have undergone many mutations not participated in by the overlying Mendon series and must therefore be separated by an uncon formity.

The conglomerate-gneiss horizon. — On the west side of the range, the Hitchcocks have colored in this horizon extending in scattered patches beneath the "quartz-rock" from Sunderland on the south to the Canadian boundary, thickening toward the north. A patch is shown at Sunderland and another at Wallingford. Beginning in the town of Ripton, if this interpretation be correct, it extends continuously across

the State. Between the areas indicated upon their map,[1] the writer has observed it or its metamorphosed equivalent, so it is known to extend in an unbroken line from near North Bennington the entire length of the State as a persistent characteristic horizon. At the Massachusetts line it is wanting where the Olenellus quartzite reposes discordantly upon a granitoid gneiss. On the east side of the range it is described by the above-mentioned authors as occurring in a narrow band running across the towns of Plymouth and Ludlow, and is correlated with the conglomerate horizon of the Rutland Valley. It is largely upon this eastern occurrence of the conglomerate that the anticlinal nature of the Green Mountains was hypothecated by them. The phenomena of stretching of quartz and gniess pebbles in this horizon and their destruction thereby, furnished the elder Hitchcock with the necessary confirmatory data for his then revolutionary ideas concerning the production of gneisses from conglomerates by metamorphism. About one mile north of Tyson's Furnace in Plymouth and on the south slope of Bear Mountain in Wallingford occur the now classical localities where the conglomerate was most carefully studied by him and where nearly all his illustrations were obtained. It is doubtful if two areas can be found in metamorphic regions where the change of sedimentary rocks to crystalline gneiss is better or more satisfactorily shown. It was with fear and hesitancy that the question of this new effect of metamorphism was discussed, but the carefully-elaborated arguments advanced show that a keen appreciation of the proper interpretation of the phenomena revealed there was felt by the author of this most valuable contribution to the science of geology.

The first area described (the Wallingford locality[2]) is situated about where the 1500 feet contour makes a sudden jog to the south. Here the elongation and flattening of the pebbles, their contorted character and the transition of the rock to gneiss are remarked upon.

[1] Opus. cit. Pl. I., Vol. II.

[2] Opus. cit., Vol. I., pp. 32 to 44.

In Rhode Island the Newport conglomerate with its indented and elongated pebbles was a starting point in the series of changes from an unchanged conglomerate to a gneiss, the Wallingford conglomerate being an intermediate stage of metamorphism, while the Plymouth occurrence represented the completed alteration.

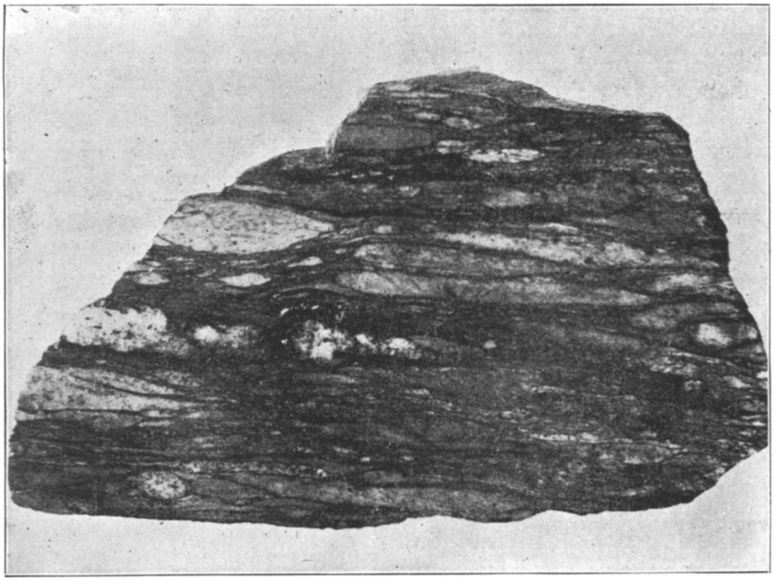

FIG. 2. Longitudinal cross-section of stretched conglomerate-gneiss. The pebbles in the upper half of the figure are mainly gneiss. In the longest pebble near the center the original lamination can still be made out. The more feldspathic clastics are now seen as thin linear films of crushed quartz and feldspar between more resistant pebbles of quartz and quartzose gneiss. From Edward Hitchcock's Green Mountain locality, one mile north of Tyson's Furnace, Plymouth, Vt. Size of block photographed 13 x 8 inches.

Much more interest was felt in this last-discovered locality where gneissic and quartz pebbles are flattened and pulled out into alternating, non-persistent bands of these minerals in a highly sugared condition, but still clearly possessing their deformed clastic outlines. Although not directly pertinent to the subject of this paper, it seems desirable to reproduce here a photograph of a block of this conglomerate, cut in longitudinal cross-sec-

tions, now in the geological exhibit of the Agassiz Museum, Cambridge, Massachusetts, Fig. 2. A fair percentage of the pebbles are of a composite nature (gneiss) and as would be expected, they have yielded most easily to the deforming forces. They now form in large part with secondarily-developed green muscovite, feldspars and cement of the pebbles, the more schistose folia of the rock. Stretching and flattening have resulted from a force operating along the plane of bedding in the direction of dip. The pebbles have been elongated most in an east and west direction, and their perceptible flattening indicates that this elongation took place under enormous load ; an environment unlike that of the pebbles at South Chittenden, which have undergone elongation without marked lateral yielding. The environment factors here were probably extreme load, a force tending to push the rock as a whole towards the west, and the presence of water charged with inorganic compounds that promoted the alteration of the clastic feldspar material, already weakened by sub-aërial decay to more stable compounds under the changed environment, and at the same time cementing the mosaic of quartz and feldspar grains resulting from the enforced granulation into a coherent rock. It seems unnecessary to postulate a high degree of temperature to account for these phenomena ; nor has plasticity, as properly defined, played any part in the deformation of the quartz and gneissic pebbles.

At North Sherburne a conglomerate occurs of considerable thickness and extends south to Ludlow, a distance of twenty-five miles. It is fully as persistent on the east side of the range in the area under discussion, as on the western, and, although some phases are unlike the western belt as a whole, it may be safely correlated with the conglomerate-gneiss horizon making, as first suggested by Adams, an anticlinal axis between Plymouth and Rutland valleys.

The question of the relations of the conglomerate-gneiss to the lower or Mount Holly rocks, has been most carefully studied on the western side of the range where the country is more open. At East Clarendon ; just north of South Chittenden, and at Hitch-

cock's Bear-Mountain locality, are three of the most instructive sections, where the contact relations of the two series are shown. All these sections show the relations of the two series in apparent *structural* conformity brought about by dynamic movements exercised throughout the rocks as a whole, but having a maximum obliterative effect immediately at the base of the conglomerate, since at this point the underlying rocks were best conditioned to record such action. Speaking of the transitional beds on Hoosac Mountain, between the Lower Cambrian quartzite-conglomerate horizon and the granitoid gneiss, Mr. Pumpelly writes as follows:[1] "This unabraded zone of crystalline rock," (reference is made here to the zone of semi-disintegrated rock on which the conglomerate was deposited unconformably) "which had its rigidity weakened by beginning disintegration, would, under folding, pressure, and metamorphism, show on the one hand a perfect and true transition into the parent crystalline rock, and on the other hand pass into the much younger beds through the similarity of the constituents derived from it; and an apparent conformity would be forced upon the whole series, and the time break would be masked by the foliation induced by the shearing action due to a slipping movement." An interpretation which so satisfactorily accounted for the transition obtaining on Hoosac Mountain can be as well applied to the transitions in Vermont at the base of the conglomerate, only here the terranes below are of a very variable character, and in a great part were already possessed of a gneissic habit which by rearrangement would even more readily take on the lamination of the rocks above. Wherever the conglomerate gneiss is found on the west side of the range a perfect transition to the lower rocks always exists, and all evidence of a discordance, such as obtains in more modern rocks of necessity must have been obliterated. It is thus seen that criteria applicable for the detection of more recent time-breaks have but little value where the rocks have been subjected to such powerful and repeated orographic disturbances,

[1] The Relation of Secular Rock-Disintegration to Certain Transitional Crystalline Schists, R. Pumpelly, Bull. Geol. Soc. of America, Vol. II., p. 215.

unless the conglomerate itself be taken as sufficient proof of an unconformity.

A practical difficulty was first met in finding a source for the abundant pebbles of blue quartz which occur so plentifully in the rock, and although sources for them are known, the proportion of such material seems to bear no proper relation to the known extent of rocks in the Mount Holly series that would be likely to yield pebbles of this mineral. Reference has already been made to a coarse phase of the conglomerate near South Chittendon where its clastic quartz best deserves the name of boulders. Such coarse phases are exceptional. An unusually coarse variety occurs one mile north of Mendon village. With the quartz pebbles there is a plentiful sprinkling of gneiss pebbles, varying in size from small grains up to two feet in diameter. Clastic areas of orthoclase are also numerous; pebbles two inches in diameter being the largest. Under the microscope abundant small grains of detrital feldspar can be detected. At this locality the original character of the rocks seems best preserved of anywhere that it is known to me, and a careful comparison of its gneissic clastics with the gneisses of the lower series immediately subjacent was made in hopes of being able to refer the pebbles to their sources. Macroscopically there appears to be no doubt that most of the pebbles were derived from the complex of gneisses to the east, and in the days before microscopical methods were used such a source would have been unhesitatingly affirmed. But today the microscope instead of simplifying one's difficulties apparently only adds to them. It is seen that the conglomerate here has recorded the evidence of dynamic action to a somewhat less extent than in many localities, but still an evident effect of metamorphism is observed. The micro-study of the lower gneiss shows them to be coarse to fine, irregularly-laminated orthoclase rocks in which both quartz and feldspar are badly crushed and distorted. About the resulting mosaics have been developed abundant epidote and titanite crystals and patches of biotite, colorless muscovite and chlorite. In the clastic gneiss little or no epidote or titanite can be detected, while there is always present more or less pale-green

pleochroic muscovite, that characterizes the conglomerate-gneiss horizon and give to it its greenish color, the result of alteration of a potassium feldspar during dynamic movement. Its other constituents seem to be identical with the neighboring gneisses, but on so slim a basis it is not deemed safe to refer the clastics to any particular gneiss area in the Mount Holly series. The feldspar clastics appear to have been derived from the pegmatite veins that are very abundant in the lower rocks to the east.

The Bear Mountain locality in some respects is more important in its bearing on the question of non-conformity than the one above described; no one area furnishes the data for all the conclusions to be drawn from the horizon. Attention was first called to the abundance of small clastic pebbles of feldspar occurring there, by Edward Hitchcock in 1861,[1] and in 1891, by Mr. Wolff.[2] As remarked by Mr. Pumpelly,[3] there seems to be "no other source than the débris of the deeply decayed Mantle" on which the conglomerate was lain down, and as such they point to a land surface close at hand where sub-aëreal decay had weakened the cohesion of the rocks, permitting a positive movement of the sea to build the more superficial mantle containing the feldspar grains, and a lower semi-disintegrated zone of gneiss and loosened blocks of gneiss into a conglomerate. The phenomenon of false bedding is well shown here, and was figured by Hitchcock[4]; transitions from coarse sediments, when the pebbles of quartz attain a diameter of nearly a foot, to fine material, point to the ordinary conditions obtaining along our coast. So, too, the outlines of the clastics are those that are characteristically produced by wave action, unless deformation has taken place, which is usually the case at this locality. All these facts are subordinate in their value compared to the conclusion to be drawn from the conglomerate-gneiss horizon as a whole, extending as it does across the State of Vermont, and presenting in one

[1] Opus. cit. p. 34.

[2] Metamorphism of Clastic Feldspar in Conglomerate Schist. Bull. Comp. Zoöl., Vol. XVI., pp. 173 to 183.

[3] Opus. cit., p. 211.

[4] Opus. cit., p. 32.

place or another all the eminent characteristics of a basal conglomerate.

An apology may be in order for dwelling so long upon the evidence detailed in support of the conclusion that an unconformity occurs at the base of the conglomerate, when, to many, the evidence afforded by the conglomerate alone would he considered amply sufficient; but in an area so greatly disturbed and metamorphosed as this, it seems best to enumerate all possible criteria that can be legitimately advanced tending to sustain the above conclusion.

SUMMARY.

To summarize briefly, this paper is hoped to have substantiated essentially the following facts:

1. That immediately beneath the Lower Cambrian quartzite in Vermont there is a series of more or less metamorphosed clastic rocks of no inconsiderable thickness; the upper member of this series being a dark chloritic mica schist; the lower member a highly metamorphosed conglomerate, and between these several pebbly limestones and pebbly micaceous quartzite strata. Evidence for and against an unconformity at the top of the schist is presented, but no satisfactory data are advanced to sustain either interpretation. The evidence for a time-break at the base of the conglomerate is thought to have been established, and the data in support of this conclusion are discussed in some detail. These rocks are referred to the Algonkian Period and are provisionally called the Mendon series.

2. That below the Mendon sedimentary rocks, a still older, more metamorphosed and more variable series of stratified rocks of Algonkian age occurs, together with gneisses and schists, whose origin is unknown, and abundant metamorphic equivalents of old basic igneous rocks. Many of the varieties of rocks occurring in this series are enumerated, and, together with their structure are contrasted with the rocks of the Mendon series, whose basal member, the conglomerate, delimits the series above. From their typical development in the town of Mount Holly, Vt., it is suggested that these rocks be called the Mount Holly Series.

CHARLES LIVY WHITTLE.